THE UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR ..Robert R. CORBETT..........................

TITLE OF THESIS ..Comparison of High Moisture and Low Moisture

..Cereal Grains in Swine Diets.............

....

DEGREE FOR WHICH THESIS WAS PRESENTED ..M.Sc. in Animal Nutrition

YEAR THIS DEGREE GRANTED ....Spring, 1973.......................

THE UNIVERSITY OF ALBERTA

COMPARISON OF HIGH MOISTURE AND LOW MOISTURE CEREAL GRAINS IN SWINE DIETS

by

 Robert Richard Corbett

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE IN ANIMAL NUTRITION

DEPARTMENT OF ANIMAL SCIENCE

EDMONTON, ALBERTA

SPRING, 1973

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "Comparison of High Moisture and Low Moisture Cereal Grains in Swine Diets" submitted by Robert Richard Corbett, B.Sc., in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

A 2x3x2x2 factorial experiment was designed to compare the performance and carcass characteristics of starting - growing - finishing pigs. The factors were: cereal source (wheat and barley), treatments (low moisture content grains, low moisture content grains with added volatile fatty acids and high moisture content grains preserved with volatile fatty acids), sex (barrows and gilts) and replicates. The volatile fatty acid mixture contained 2/3 acetic and 1/3 propionic acids. The moisture contents of the low moisture wheat and barley were 14.2%, high moisture wheat was 19.9% and high moisture barley was 25.5%. The diets were formulated to contain 17.4% protein on a dry matter basis.

Pigs fed barley-based diets consumed more feed per day, gained at a faster rate and had better feed conversion efficiencies than pigs fed wheat-based diets. Treatments had no significant effects on performance of the pigs from weaning to 90 kg liveweight. Barrows gained at a faster rate than gilts but daily feed intakes and feed conversion efficiencies were not different between sexes during the starting period which is the only period where sexes were fed separately.

Barley-fed pigs reached market weight at a younger age and produced superior carcasses than did wheat-fed pigs. Volatile fatty acid treatment of cereals increased slaughter age of pigs by approximately 10 days. Pigs fed barley-based diets had a larger proportion of saturated fatty acids and concomitantly less unsaturated fatty acids in the back fat than those fed wheat-based diets. Treatments had no significant effects on the carcass characteristics or proportions of saturated and unsaturated fatty acids in the back fat.

Gilts produced superior carcasses compared with barrows. There were more unsaturated and less saturated fatty acids in the outer back fat layer of the gilts.

The data suggest that high moisture barley preserved with a mixture of acetic and propionic acids may be substituted for low moisture barley on a dry matter basis for pigs. The data also suggest that similar substitutions may be made between high moisture wheat with preservative and low moisture wheat but the results are not as unequivocal as those with barley.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. L.W. McElroy, Head of the Department and Professor of Animal Science for placing the facilities of the department at his disposal.

For the guidance and advice of Dr. J.P. Bowland, Professor of Animal Nutrition throughout the course of this study and for his constructive criticisms during the preparation of this manuscript, I am deeply indebted.

Thanks are extended to Dr. R.T. Hardin, Associate Professor of Poultry Genetics for his help with the statistical analyses. The able assistance of Mr. G. Stephens, Swine Herdsman, The University of Alberta Edmonton Research Station and his staff during the course of this study is hereby acknowledged.

The patience, cooperation and encouragement afforded me by my wife, Sharon, throughout the course of this study is gratefully acknowledged.

Financial support for this study provided by the Alberta Agricultural Research Trust and Celanese Canada Limited is hereby acknowledged. The provision of experimental cereals by Celanese Canada Limited (formerly Chemcell Ltd.) is also acknowledged.

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INTRODUCTION

Relatively little work has been reported in the literature comparing wheat with barley as the sole cereal grains in swine diets. This has been in part due to the relatively high cost of wheat which has usually been considered as a human food unless the grain was of low quality. Recent economic conditions affecting the price of wheat and the introduction in Canada of new varieties of feed wheats, now referred to as utility wheats, has led to renewed interest in balanced diets composed of high levels of wheat. It therefore seemed desirable to investigate the relative merits of diets based on wheat compared with barley on the performance and carcass characteristics of pigs.

Weather conditions and length of the growing season in some parts of Western Canada are such that it is often difficult to harvest grain at a moisture content low enough to enable storage under conventional conditions without artificial drying. In recent years, volatile fatty acids (VFA) have been used as preservatives for high moisture content grains. As this is a relatively new method of storage, an experiment was designed to investigate the effects on performance and carcass characteristics of pigs when they were fed barley or wheat-based diets containing no VFA or low levels of added VFA to low and high moisture grains.

LITERATURE REVIEW

General comparison of wheat and barley in diets for swine

Cereal grains commonly constitute the major source of energy in diets for swine. Because typical pig diets contain large amounts (over 80 percent) of cereals, a substantial portion of the dietary protein also comes from grains.

The relative merits of wheat and barley in providing energy, protein and essential amino acids, particularly lysine, for growth and maintenance of the pig may be gained by inspection of NRC Feed Composition Tables (1969). Wheat and barley vary in protein and energy content depending on variety and location at which they are grown; however, as a source of digestible energy (DE) wheat is generally superior to barley. This observation is in agreement with Cornejo et al. (1973), Robinson et al. (1965) and Henry (1968). The crude protein and digestible protein content of wheat is also superior to that of barley. The lysine content of wheat is generally slightly less than that of barley on an equal weight basis and much less on a protein equivalent basis. Chamberlain (1969) has assigned wheat a value for energy content of 114% and for protein and lysine of 103% the value of barley. These values are based partially on economics and are probably valid at only one point in time. There are no major or consistent differences in mineral or vitamin content between barley and wheat (NRC Feed Composition Tables, 1969).

Diets based on wheat and barley as the sole source of energy and protein

It has been known for many years that diets based on cereals unsupplemented with protein do not support adequate rates of gain (ADG) and efficiencies of feed conversion (F/G) when compared with balanced diets.

It is widely accepted that the ingredients supplied in a balanced diet, other than the cereal source, play a definite role in determining the performance of pigs fed these diets.

In a series of trials, Bowland and Berg (1959) demonstrated the superiority of a balanced diet in improving ADG, F/G and daily feed intake (ADF) over diets containing wheat and barley as the only sources of protein and energy. Over a ten week feeding period, weanling pigs fed a balanced control diet gained approximately three times faster, consumed twice as much feed and required three quarters as much feed per kilogram of gain compared with pigs fed wheat and barley supplemented only with minerals and vitamins. The barley-fed pigs gained faster, consumed more feed and required more feed per unit of gain than did wheat-fed pigs. Henry (1968) reported similar findings for pigs in the "finishing period". Robinson et al. (1965) reported similar rates of gain for barley and wheat-fed pigs but non-significantly better F/G for barley diets from 55 to 90 kg. Bellis and Taylor (1961) reported superior ADG and F/G for barley than for wheat for 55 to 105 kg pigs.

In cases where wheat or barley constitute the sole source of protein and energy, it appears that barley is superior to wheat. This is probably associated with the better ratio of protein to DE and the higher lysine content in barley. In diets of this nature, energy content would not be a limiting factor.

Wheat and barley in balanced diets for pigs

The use of high levels of wheat in diets for pigs has recently become of greater interest in western Canada. Wheat has been used to varying extents for many years. The introduction of new varieties of feed wheats, now referred to as utility wheats, and most importantly recent

economic conditions have led to its use at high levels. For a general discussion of wheat as a pig feed, the reader is referred to Wheat in Livestock and Poultry Feeds (1970). Comparisons in the literature of wheat and barley as the only cereal source in swine diets are few.

Effects on ADG, F/G and ADF

Most of the work reported in the literature concerning high levels of wheat or barley in pig diets has been done with diets containing equal amounts of the cereals supplemented with a standard protein, mineral and vitamin supplement. In general the wheat-based diets are of higher caloric density than the barley-based diets.

In a series of experiments, (Cole et al., 1969), diets containing approximately 83% and 86.5% of wheat or barley in starting and finishing diets respectively were compared. The DE:protein ratios were calculated to be similar for the wheat and the barley-based diets. In the first of these trials, ADG were similar at 0.56 kg/day for the wheat-fed pigs and 0.58 kg/day for the barley-fed pigs to 90 kg liveweight. No significant difference in F/G was reported but barley-fed pigs consumed more ($P < .001$) feed per day and had a greater (not significant) DE intake than the wheat-fed pigs. During the second trial, there was no difference in ADG or F/G for pigs fed either diet. The barley-fed pigs consumed more feed (1.87 kg/day) than the wheat-fed pigs (1.83 kg/day) which resulted in no significant differences in DE intake. A third trial was carried out in which barley-fed pigs gained slightly more rapidly (0.64 kg/day) compared with those fed wheat (0.61 kg/day). F/G did not differ between the diets but barley-fed pigs ate slightly more feed and consumed similar amounts of DE. In the last trial of this series, ADG and ADF were not different between the pigs fed the two diets; however, the barley diets were better utilized

than the wheat diets ($P < .01$).

Similar trials designed by Chamberlain (1969) in which diets containing a minimum of 76% of wheat and barley and equalized as to protein:DE ratios and lysine:DE ratios were compared. These diets were fed to 90 kg liveweight with the pigs being given equal amounts of dry matter and, therefore, equal DE. In the first of these trials where DE:protein and DE:lysine ratios were calculated to be equal, the barley-fed pigs gained more rapidly at 0.60 kg/day compared with 0.56 kg/day for the wheat-fed pigs but converted feed less efficiently at 3.15 kg feed/kg gain and 3.00 kg feed/kg gain respectively. In a second trial, the DE:protein and DE: lysine ratios were equalized using data from the analysed ingredients. In this case, ADG were similar for both diets and F/G was better for the wheat-based diet (3.00 kg feed/kg gain) than for the barley-based diet (3.25 kg feed/kg gain). It would appear that under the circumstances just described these cereals support similar rates of gain with a slightly superior efficiency of feed conversion in pigs fed wheat-based diets compared with barley-based diets.

When wheat is substituted in a diet at equal rates with barley without adjustments for the energy:protein ratios, it might be expected that wheat should support faster growth rates than barley due to expected higher caloric density of the wheat-based diet. Lawrence (1968) conducted an experiment comparing these cereals at 85% and 90% inclusion in starting and finishing diets respectively. Diets contained the same quantity of a standard supplement. ADG were not significantly different between the two diets averaging 0.67 kg/day for wheat and 0.67 kg/day for barley. F/G for wheat (2.86 kg feed/kg gain) was similar to that of the barley (2.91 kg feed/kg gain). However, DE/kg gain was superior for the barley diets at

1.73 Mcal/kg than for wheat diets at 2.02 Mcal/kg ($P < 0.001$). A second experiment (Lawrence, 1970) designed in the same manner was carried out. Growth rates were similar between the wheat (0.70 kg/day) and barley (0.70 kg/day) diets. The F/G were not significantly different at 2.73 kg feed/kg gain for wheat and 2.83 kg feed/kg gain for barley. The DE was converted to gain slightly less efficiently for wheat than for barley diets (1.86 Mcal/kg vs 1.72 Mcal/kg). The lack of response in ADG in these trials to the increased caloric density of the wheat diets compared with the barley diets may have been due to the method of feeding. Feed was offered to the pigs based on a scale linking feed offered to live-weight.

Ad libitum feeding of diets containing high levels of wheat and barley should allow these cereals to exhibit their relative merits to the fullest extent in terms of ADG, ADF and F/G. With starting pigs for an eight week period from 3 1/2 weeks of age, Bowland (1967) compared diets based on wheat, hulless barley or heavy barley (50 lb to the bushel). All diets contained 60.9% of the appropriate cereal so that calculated DE/kg diet and crude protein by analyses decreased from the wheat to hulless barley to barley-based diets respectively. ADG averaged 0.50 kg and F/G averaged 2.01 kg feed/kg gain and did not differ among pigs fed the three diets. Lennon et al. (1972) compared diets based on approximately 85% wheat and barley. The pelleted diets containing 15.5% crude protein were offered *ad libitum* to 22 kg pigs over a 91 day experimental period. The growth rates of the pigs on these diets were similar, 0.86 kg/day for barley and 0.84 kg/day for wheat. Barley-fed pigs ate more ($P < .01$) feed; however, F/G was superior ($P < .05$) for the wheat-fed pigs. Wheat, regular barley and hulless barley were compared (Gill et al.,

1966) when these cereals constituted 80% and 85% of starting and finishing diets respectively supplemented with equal quantities of a standard protein, mineral and vitamin supplement. The diets were fed _ad libitum_ to 28 kg pigs for a 63 day trial period. The hulless barley and the wheat-fed pigs had similar growth rates and both were superior ($P < .05$) to pigs fed regular barley. The F/G were similar for wheat-fed pigs (3.49 kg feed/kg gain) and hulless barley-fed pigs (3.29 kg feed/kg gain) and both were superior ($P < .05$) in F/G to the regular barley-fed pigs at 3.97 kg feed/kg gain. Diets compounded with wheat and barley (Hollis and Palmer, 1971) to contain 17% and 15% crude protein in starting and finishing periods respectively were shown to produce similar results for ADG, ADF and F/G. On these diets, wheat-fed pigs gained 0.66 kg/day, consumed 2.44 kg of feed per day and required 3.61 kg feed/kg gain compared with barley-fed pigs which gained at a rate of 0.68 kg/day, consumed 2.40 kg feed per day and required 3.66 kg feed/kg gain. Crampton and Ashton (1945) reported similar findings for pigs fed 85% and 90% of wheat and barley in starting and finishing diets respectively supplemented with a constant formula protein and mineral supplement. Although ADG and ADF were not significantly different between pigs fed either diet, the "gains adjusted to average feed" were significantly superior for the pigs fed the wheat-based diet.

It would appear from the evidence in the literature that for either cereal, wheat or barley, there are substantial variations in ADG and F/G ratios. This could be due to genetic and environmental influences on the cereal sources or on the animals being fed, as well as feeding method. The variation in nutrient content, especially protein and energy, between samples of the same cereal play an important role in

determining the performance of pigs fed that cereal. The evidence suggests that with balanced diets, barley is usually similar to wheat in terms of value. Efficiencies of feed conversion may be superior for pigs fed wheat-based diets because of the higher DE content of wheat compared with barley.

Digestibilities of energy and nitrogen

There is a paucity of information concerning the comparative digestibilities of diets based on high levels of wheat and barley. Lawrence (1968) comparing diets containing 85% and 90% of wheat and barley in starting and finishing diets respectively, found a greater apparent digestibility coefficient of dry matter ($P < .001$) in favor of the wheat-based diet although N digestibility coefficients were not significantly different. The digestibility coefficients of gross energy were greater for wheat-based diets, 82.5% and 85.2% for the starting and finishing diets respectively, than for barley-based diets at 70.5% and 77.0% in the starting and finishing diets respectively. The composition of feeds tables in the NAS-NRC Nutrient Requirements of Swine (1968) list DE values for barley ranging from 2896 to 3214 kcal/kg on an 'as fed' basis of 90% dry matter (DM). DE values listed for wheat on a similar basis range from 3388 to 3569 kcal/kg.

Carcass characteristics

The use of high levels of wheat and barley in the diets of growing-finishing pigs has no significant effect on carcass length (Lawrence, 1968, 1970; Crampton and Ashton, 1945; Hollis and Palmer, 1971). Hollis and Palmer (1971) and Lawrence (1968, 1970) found no significant differences in loin eye area between pigs fed wheat and barley, a result which differs from that of Crampton and Ashton (1945) who reported a significant

increase in loin eye area for pigs fed barley-based diets ($P < .05$). Greater back fat thickness ($P < .05$) for wheat-fed pigs has been reported by Hollis and Palmer (1971) which is not in agreement with Gill et al. (1966) who found no significant differences in backfat thickness between wheat and barley-fed pigs. Lawrence (1968, 1970) also reported non-significant differences between pigs fed wheat and barley in the amount of lean and fat in the carcasses although barley-fed pigs tended to be slightly leaner. Superior dressing percentages ($P < .05$) in favor of wheat-based diets have been reported by Hollis and Palmer (1971). A superior killing-out percentage (dressing percentage) has been reported in favor of barley-based diets ($P < .01$) in one of four trials (Cole et al., 1969). In three of these trials there were no significant differences in this measure. Therefore, there is little agreement as to whether barley and wheat diets influence dressing percentage.

The evidence suggests that high levels of barley or wheat in diets for pigs will produce similar carcass characteristics although wheat-fed pigs may tend to be fatter which is probably associated with the higher DE intake which may occur when pigs are fed diets based on wheat compared with barley.

High moisture content cereals

It is well known that high moisture content grain is subject to deterioration caused by microbial growth, especially fungi, and that such cereals can affect the performance of pigs. The method of storage as opposed to moisture content itself, may be the most important factor in determining feeding value. Grain harvested at a high moisture content is usually artificially dried before storing to prevent microbial growth and spoilage. Cereal grains such as wheat and barley are usually dried to

approximately 14% moisture content (m.c.).

Performance of pigs fed high moisture cereals

Livingstone and Livingston (1970) conducted a series of experiments comparing dried and moist (26% m.c.) barley in diets for growing-finishing pigs. The moist barley was stored in a silo under a CO_2 atmosphere until milled and then placed in sealed plastic bags. The pigs were given equal amounts of feed (not on a DM basis) over the feeding period. The ADG and F/G of the pigs fed moist barley were not significantly different from those receiving the dried barley. In a subsequent experiment, when feed intakes were adjusted to give the same quantity of DM, the pigs fed dried barley grew faster ($P < .001$) and converted feed DM more efficiently ($P < .001$) than those fed moist barley. Rolling and grinding of the dried and moist barley did not affect the performance of the pigs. The moist barley-fed pigs gained at a slower rate ($P < .05$) and required more feed DM per unit of gain ($P < .05$) than did pigs fed dried barley irrespective of processing. Subsequent drying of the silo-stored moist grain before feeding did not significantly improve the performance of pigs fed this diet over the moist barley diet. In this case, the pigs fed dried barley gained at a faster rate ($P < .10$) and converted feed more efficiently ($P < .01$) than did pigs fed the moist grain and the moist grain which had been dried at the time of removal from storage. This would indicate that changes during storage of the moist barley had occurred. In later trials, (Livingstone et al., 1971), the microbial growth in diets compounded with dried barley and moist barley (29% m.c.) was monitored. The moist barley was stored in sealed polyethylene bags. The pigs fed dried barley exhibited superior growth rates ($P < .01$) and efficiencies of feed conversion ($P < .01$) when compared with moist barley-fed pigs when the pigs were fed

equivalent amounts of DM. The numbers of bacteria isolated from the dried barley were broadly similar to those on the moist barley; however, the numbers of fungi were always no less than 500 times greater on the moist barley samples.

Similar work with barley was carried out by Cole et al. (1970) comparing dried and moist (19% m.c.) grain. In this experiment, the high moisture content barley-fed pigs gained at similar rates and converted feed DM as efficiently as those fed artificially dried barley. Similar findings by Forbes et al. (1963, 1964) were reported for silo-stored high moisture barley (25% m.c.) versus dried barley. Young (1970) reported that pigs fed artificially dried corn had growth rates, dry matter intakes and efficiencies of feed conversion similar to pigs fed corn of 32% moisture content. When 40.5% moisture content corn was fed, rates of gain and dry matter intakes were inferior ($P < .05$) to the pigs fed dried corn. Since the DE contents of the diets on a DM basis were similar, the drop in growth rate was probably due to the lower feed intakes on the 40.5% moisture corn. Jamieson et al. (1967) noted that barrows fed air-dry versus high moisture barley (33% to 40% m.c.) "were on feed the least time" indicating no adverse effects on the performance of pigs due to the high moisture content of the barley. In a series of experiments, Conrad et al. (1958) found that pigs fed high moisture corn gained 3% faster, 5% faster or equally as fast as pigs fed dried corn.

High moisture grain when properly stored, does not appear to affect growth rate or efficiencies of feed conversion of pigs. There is some evidence that method of storage may affect the feeding value of grain possibly due to fungal growth or changes in the grain during storage. It was frequently noted in the literature reviewed that high moisture grain

will "heat" soon after being placed in feeders or otherwise left open to the air.

Digestibilities of energy and nitrogen

The moisture content of grain does not appear to affect the apparent digestibility coefficients of the different fractions of the diets. Kornegay et al. (1968, 1968) reported no significant differences in the apparent digestibility coefficients of DM, protein, ether extract, crude fiber and N-free extract or N retained for pigs fed diets reconstituted to 40% and 55% moisture content (of the diet) as compared with the dry diet. Similar findings (Cole et al., 1970) were reported for the digestibility coefficients of DM, N and gross energy between pigs fed high moisture and dried barley diets. Livingstone et al. (1971) reported digestibility coefficients for DM of 82.5% for dry barley and 81.3% for moist barley and for N of 84.7 and 82.2% for dry and moist barley diets respectively.

Carcass characteristics

The use of high moisture grain in pig diets does not appear to significantly effect carcass composition. Cole et al. (1970) showed no significant differences in measures of killing-out percentages, carcass length or backfat thickness between pigs fed diets compounded with dry and moist barley. Breidenstein et al. (1964) observed no significant differences for loin eye area, loin marbling, percent fat in the *longissimus* muscle or percent free moisture in the *longissimus* between pigs fed corn at three moisture levels (12%, 20% and 25% m.c.). Gross carcass composition as measured by specific gravity of half carcasses were shown to be similar for pigs fed dried and high moisture content barley (Forbes et al., 1964; Livingstone and Livingston, 1970; Livingstone et al., 1971). Area of the loin eye has been shown not to be affected by moisture content of dietary

barley (Livingstone and Livingston, 1970). Forbes et al. (1964) reported that backfat thickness was not affected by feeding moist barley which is in agreement with the findings of Livingstone and Livingston (1970).

Volatile fatty acid (VFA) preservation of high moisture grain

VFA and other short chain fatty acids have been found in the digestive tract, blood and feces of the pig (Friend et al., 1962, 1963, 1963, 1964). The acids present include acetic, propionic and butyric as well as other VFA and lactic acid. These acids for the most part are produced in the alimentary tract by microbial fermentation. In the young pig (Friend et al., 1963) the concentration of VFA (C_1 - C_5) and lactic acid tend toward uniformity throughout the alimentary tract up to about one week of age. The concentration of these acids tends to decrease in the upper part and increase in the lower part of the tract with age. The addition of whey to a control diet for these pigs did not appear to affect the presence of butyric, acetic or propionic acids in the tract. Reduction in the percent of lactic acid accompanied by an increase in acetic and propionic acids in the tract occurred at 5 weeks of age which may have been related to introduction of solid feed. For older pigs, 70 to 90 kg, the type of diet fed (control, bran-supplemented and cellulose-supplemented) did not affect the levels of butyric, acetic and propionic acids in the alimentary tract (Friend et al., 1963). The highest proportions of these acids occurred in the large intestine which is the only portion of the alimentary tract with significant amounts of organic acid (Elsden et al., 1946; Cole et al., 1968). These acids and other VFA and short chain fatty acids have been isolated from the feces of pigs (Friend et al., 1962) as well as carotid and portal blood (Friend et al., 1964). In carotid and portal blood, lactic acid represents

greater than 55% of the C_1 to C_5 volatile fatty acids and lactic acid, followed in importance by formic acid (approximately 25%) and acetic acid (approximately 15%). Lesser quantities of propionic and butyric acid have been found. Acetic acid represented 97.8% and 86.7% of the total acetic, propionic and butyric acids present. Friend et al. (1964) calculated a possible energy contribution by VFA (acetic, propionic and butyric acids) from alimentary sources. Using determined arterial-venous difference and values for blood flow rate and heats of combustion from the literature, a possible contribution of 15 to 28% of the maintenance energy requirement of a 30 kg pig could be met.

The chief sites of absorption of VFA in the pig are the caecum and proximal colon (Barcroft et al., 1944). When short chain fatty acids are fed in the diet to pigs they are probably absorbed and quickly metabolized. When butyric and caprylic acids were fed in the diet of sows (Witter and Rook, 1970) there was no detectable transfer of these acids to plasma triglycerides which would indicate rapid catabolism of short-chain fatty acids. Freeman et al. (1970) showed that endogenous production of acetate is quantitatively more significant than acetate absorbed from the alimentary tract but that there was a contribution of acetate from alimentary sources.

Addition of substantial quantities of VFA appear to be well tolerated by growing-finishing pigs. Bowland et al. (1971) conducted an experiment to study the acceptability and performance of pigs fed diets containing a VFA mixture (40 acetic: 40 propionic: 20 butyric by weight percent) and the sodium salts of these acids. Substitution of up to 8% by weight of these two mixtures into a control diet did not adversely affect rates of gain or feed intake of the pigs as compared with pigs fed a control diet

with no added acid mixture. The addition of 10 and 12% of the mixtures depressed growth rate ($P < .05$) and feed intake ($P < .05$). When 4% of these mixtures were substituted in the diets of growing-finishing pigs, ADG and ADF were not significantly affected. F/G over the total period from 12 kg liveweight until slaughter were not significantly different between the control pigs and the pigs fed diets containing the mixtures of VFA and Na-VFA; however, during the 38 kg to 75 kg liveweight feeding period, the pigs given the acids and sodium salts of the acids demonstrated slightly superior ADG which was reflected in their superior F/G ratios. There was also an apparent improvement in calculated DE conversion efficiency by the pigs fed the acid and salt mixtures during this period. This superiority could not be accounted for by energy contribution of the VFA mixture and the salts of these acids alone. A possible "synergistic action" with other energy sources in the diet was suggested as a reason for the superiority. There were no significant differences in several measures of carcass characteristics including grade index, dressing percentage and average backfat thickness between control pigs and pigs fed the VFA mixture and the mixture of the sodium salts of these acids.

The effect of addition of 0.8% of lactic acid, propionic acid, calcium propionate and calcium acrylate to the drinking water of pigs on performance and bacterial flora of the gut has been studied by Cole et al. (1968). The treated water was added to the feed at the rate of 2.5 kg water per kg feed which would represent approximately 2% addition to air dry feed. For the four-week trial period post-weaning, treatments did not significantly effect efficiencies of feed conversion. Pigs fed calcium acrylate apparently found this compound unacceptable as feed intakes and growth rates were poorer ($P < .05$) than for controls. Pigs fed propionic

acid and calcium propionate in their diets had ADG and ADF similar to the controls. During an eight week period after treatments were withdrawn, no significant differences in performance and feed utilization were exhibited by any of the groups of pigs. The bacteriological study indicated that all compounds used were effective in controlling haemolytic E. coli and reducing counts of non-haemolytic E. coli in the gut during the treatment period.

In summary, acetic, butyric and propionic acids are commonly found at low levels in the gut of the pig and may contribute toward maintenance and other energy requirement. Short chain fatty acids from the diet are absorbed and rapidly metabolized. Addition of up to 8% of VFA in the diet of growing-finishing pigs does not appear to adversely effect performance or carcass characteristics of the pig.

VFA preservation of high moisture grain is a relatively new method of storing "wet" grain. VFA including acetic, propionic and formic acids have been used as preservatives for damp grain in Great Britain where damp grain is a continuing problem and more recently has become of interest in North America. Addition of VFA, singly or in mixtures, to moist grain lowers the pH to approximately pH 4 and effectively suppresses microbial growth (Holden, 1972). Rates of VFA application commonly range between 1.5 and 0.8% by weight of the DM content of the grain. Rates of application depend on moisture content of the grain and desired length of storage. VFA-treated high moisture grain can be safely stored under normal conditions even after milling or rolling. Some feed refusals due to acid treatment have been noted (Collier, 1969) when cattle were fed "freshly" treated grain. This has been attributed to the acrid odor of freshly treated grain, especially when propionic acid is used.

The odor disappears within a few days after treatment.

Effects on ADG, F/G and ADF

Livingstone et al. (1971) conducted an experiment comparing the performance of 30 kg pigs fed diets based on dried barley (14% m.c.), propionic acid-treated barley (24% m.c.) and high moisture untreated barley (29% m.c.). Propionic acid was added to the high moisture barley at the rate of 1.3% by weight. Over the eleven week trial, pigs fed the dried barley diet had ADG and F/G similar to the pigs fed the acid treated barley while those fed the moist hermetically stored barley grew more slowly ($P < .01$) and converted feed less efficiently ($P < .01$) than those fed the other two diets. Microbiological studies demonstrated the ability of the propionic acid to suppress microbial growth. There was no significant development of bacteria or fungi on the acid-treated barley which was in contrast to the substantial microbial growth on the dried and moist untreated barley. Bacterial numbers isolated from the dried and moist barley were similar; however, the numbers of fungi were always at least 500 times higher for the moist untreated barley than for the corresponding sample of dried barley. A similar trial compared diets compounded with dried barley (14% m.c.), acid-treated high moisture barley (17% m.c.) and hermetically stored high moisture barley (19% m.c.). When the barley was milled, the acid-treated grain diets gave ADG and F/G similar to the dried barley. Rolling of the high moisture barley, treated and untreated with acid, significantly reduced ADG and F/G ($P < .001$) during the growing, finishing and overall periods. There were no significant differences as measured by these parameters between pigs fed acid treated and hermetically stored high moisture rolled barley. Perez-Aleman et al. (1971) conducted an experiment comparing convention-

ally dried barley and high moisture barley treated with 1.3% of an acid mixture (70% formic: 30% propionic). The high moisture grain was 26 to 28% moisture content at harvest. Acid treatment did not significantly effect feed consumption on an 'as fed' or a DM basis; however, F/G was better ($P < .01$) for pigs fed dried barley on an 'as fed' basis. This difference was eliminated when F/G was equated on a DM basis. Growth rates of the pigs were not significantly different. When the diets compounded with these grains were fed on a restricted equal DM basis there were no significant differences in terms of ADG or F/G (on a DM basis) between the groups.

Comparisons of diets compounded with dried grains and acid-treated dried grains other than barley or wheat have been conducted by several workers. Workers at Texas A & M University as cited by Holden (1972) compared sorghum-based diets in which the sorghum was dried, and treated with 0.4% of a VFA mixture (60% acetic: 40% propionic acids), and high moisture sorghum (24 to 36% m.c.), part treated with 3.4% weight percent of the acid mixture and part hermetically stored. There were no significant differences between the pigs on the four treatments with regard to DM feed intake, F/G or ADG. Similar trials with corn-based diets have been conducted by Young et al. (1970). High moisture content corn (26% m.c.) stored in a plastic lined silo and some treated with 1.5 weight percent propionic acid were compared with artificially dried corn, part of which had been treated with 1.5 weight percent propionic acid. In the first trial 22 kg pigs were fed the four diets for an eight week period. During the period DM feed intakes, ADG and F/G were not affected by moisture content or acid treatment. However, significant interactions between moisture content and acid treatment did occur.

The addition of acid to dried corn decreased ($P < .05$) DM feed consumption and addition of acid to moist corn increased ($P < .05$) DM feed consumption without significantly affecting F/G or ADG. In a subsequent 9 week trial using these diets for 27 kg pigs, moisture content did not affect ADG or DM intake. Addition of acid significantly increased ADG ($P < .05$) but did not affect ADF. The pigs fed dried untreated corn required more feed per unit of gain ($P < .05$) than any of the other treatment groups which were not different. Jones et al. (1970) compared diets containing ensiled corn and propionic acid treated corn (1.5 weight percent) at a moisture content of approximately 31%. The diets were fed _ad libitum_ to 26 kg pigs for an eight week period. No mould colonies were found in acid treated corn but 1200 colonies per g were isolated from the ensiled corn. Pigs fed the acid-treated corn grew 11.1% more rapidly ($P < .01$) than those fed ensiled corn. Although not significantly different, the pigs fed acid treated corn consumed 4.2% more feed with 6.1% better F/G than those pigs fed ensiled corn.

In all studies cited in this manuscript, acid-treated high moisture content grain was stored under aerobic conditions. There were no reports of adverse effects on the general health of pigs attributed to acid treatment of grain used in the diets. Volatile fatty acids are effective preservatives for high moisture feed grains. The evidence suggests that growth rates and efficiences of feed conversion are similar for VFA treated high moisture grains compared with conventionally dried grains.

Digestibilities of energy and nitrogen

Work cited by Holden (1972) reported that the apparent digestibility coefficients of gross energy and protein were not significantly affected by treatment with an acid mixture (3.4 weight percent of 60% acetic: 40%

propionic acids on high moisture sorghum and 0.4 weight percent dry sorghum); however, the apparent digestibility coefficients were significantly greater ($P < .05$) for high moisture grain than for dry grain. Cole et al. (1970) found no significant differences between dried barley, propionic acid treated high moisture barley and hermetically stored high moisture barley in DM, energy and N digestibility coefficients. In contrast to these findings, Livingstone et al. (1971) found that propionic acid treated high moisture barley was less well digested in terms of percent dry matter ($P < .05$) and percent N ($P < .01$) than artificially dried barley. Moist hermetically stored barley was intermediate between dried and acid treated moist barley for these two digestibility measures.

Carcass characteristics

With pigs fed at a restricted level, overall carcass composition, measured by carcass specific gravity, was not significantly different when barley diets which were artifically dried or VFA treated high moisture content barley were fed (Perez-Aleman et al., 1971; Livingstone et al., 1971). Pigs fed ad libitum (Perez-Aleman et al., 1971) on dried barley diets were fatter ($P < .01$) than pigs fed acid treated high moisture barley. In this case, the acid was a mixture of 70% formic: 30% acetic acids. A large proportion of the carcasses of pigs fed barley treated with this mixture showed brown to yellow fat discoloration. Dressing percentage and carcass length were not affected by feeding VFA treated high moisture barley (Cole et al., 1970; Perez-Aleman et al., 1971). Addition of 4% of a VFA mixture to pig diets based on dry ingredients has been shown not to affect dressing percentage, grade index, loin eye area, percent lean in ham face or backfat thickness (Bowland et al., 1971). Ad libitum fed pigs given VFA treated high moisture

barley had decreased shoulder ($<.01$), mid-back ($P < .01$) and loin fat ($P < .05$) thickness compared with those fed low moisture barley. Pigs fed at a restricted level gave no significant differences for these measures (Perez-Aleman, 1971). Differences in shoulder and loin fat thickness have been shown to be non significantly different when high moisture VFA treated barley was compared with dry barley fed at equal DM intakes (Cole et al., 1970).

The evidence suggests that no large differences in carcass composition result from use of grains which have been preserved with VFA. With certain mixtures of VFA, carcass fat may be discolored. This is probably associated with formic acid.

EXPERIMENTAL PROCEDURES

Objectives

This experiment was designed to compare the performance and carcass characteristics of growing and finishing pigs when they were fed diets based on wheat or barley of low moisture content, low moisture content with added volatile fatty acids or high moisture content preserved with volatile fatty acids.

Methods and procedures

Introduction

The experiment was begun on December 9, 1971, and terminated when the last pig was marketed on June 27, 1972. The entire experiment was conducted at The University of Alberta Research Station, Edmonton, Alberta.

Experimental diets

Formulation and composition of the experimental diets are given in Table 1. Analyses for moisture and protein contents of the cereal grains werecarried out prior to formulation and are summarized in Table 2. The barleys with the two moisture levels were from the same field as were the two wheats.

The experimental diets were mixed and bagged at The University of Alberta Research Station, Edmonton, Alberta. The first mix was done at the elevator on December 9, 1971 and a second mix at the feed mill on January 27, 1972. All of the diets were stored in the barn where they were fed. It was noted that at the time of the second mix, the high moisture barley froze in the storage bin. Diets containing the same levels of ingredients on the basis of formulation were fed to the pigs from the time of allotment until slaughter.

Experimental design

A. Growth studies and carcass evaluation

The experiment consistedof two replicates, both begun on December 9, 1971. All pigs were weaned at three weeks of age and were kept on a standard diet until allotment. Prior to weaning, all pigs were treated in the manner described by Grimson (1969). The pigs were of mixed breeding (Landrace x Lacombe-Yorkshire, Landrace x Hampshire-Yorkshire, Landrace x Yorkshire, Hampshire x Hampshire-Yorkshire or Hampshire x Lacombe-Yorkshire). Replicate 1 consisted of 12 gilts and 12 barrows at an average initial weight of 8.9 kg and average age of 37.2 days. Replicate 2 consisted of 12 gilts and 12 barrows at an average initial weight of 17.0 kg and average age of 55.7 days. After allotment, the pigs were self-fed with two pigs of the same sex in each of twenty-four pens measuring 0.62 m by 1.23 m.

Pigs were fed the six diets as outlined in Table 1 for seven weeks during the starting period, after which time both replicates were moved to different facilities; replicate 1 to barn F-16 and replicate 2 to barn F-15. When the pigs were moved to these facilities, two gilts and two barrows were alloted to each pen and self-fed until slaughter. The pens measured approximately 1.83 m x 4.42 m. The two pigs of the same sex had been penmates during the starting period. The barns were maintained at approximately 21°C throughout the experiment.

Feed consumption and liveweight gain were determined on a weekly basis. Feed consumption was then corrected to a dry matter basis (see Metabolism Trials i. feed). Weight gain and efficiency of feed conversion were calculated from these data. Individual pigs were marketed for slaughter following the weekly weigh day on which they reached 90 kg

Table 1. Formulation and composition of experimental diets

Diet #[1]	1	2	3	4	5	6
Cereal		Barley			Wheat	
Moisture level (grain) %	14.2	14.2	25.5	14.2	14.2	19.9
Calculated protein (% DM)	17.4	17.4	17.4	17.4	17.4	17.4
Calculated lysine (% diet DM)[2]	0.84	0.84	0.84	0.55	0.55	0.54
Calculated methionine & cystine (% diet DM)[3]	0.51	0.51	0.51	0.53	0.53	0.53
Ingredients						
Barley	815.0	805.5	833.0	-----	-----	-----
Wheat	-----	-----	-----	915.0	907.0	923.0
Soybean meal (44%)	155.0	155.0	140.0	55.0	55.0	50.0
Iodized salt	4.0	4.0	3.6	4.0	4.0	3.6
Calcium phosphate	8.0	8.0	7.2	8.0	8.0	7.2
Ground limestone	15.0	15.0	13.5	15.0	15.0	13.5
Zinc sulphate	0.25	0.25	0.225	0.25	0.25	0.25
Trace mineral mix[4]	1.0	1.0	0.9	1.0	1.0	0.9
Vitamin B mix[5]	1.0	1.0	0.9	1.0	1.0	0.9
Vitamin B_{12} mix[6]	0.5	0.5	0.45	0.5	0.5	0.45
Vitamin A mix[7]	+	+	+	+	+	+
Vitamin D_2 mix[8]	+	+	+	+	+	+
Vitamin E (Myvamix 20)[9]	0.25	0.25	0.225	0.25	0.25	0.225
Chemstor[10]	-----	9.5	+	-----	8.0	+
Total	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0

[1] Diets 1, 2, 4 and 5 contain low moisture, coarsely ground grains and diets 3 and 6 contain high moisture, coarsely ground grains (Table 2).

[2] Calculated using values from NRC Feed Composition Tables, 1969 for Canada #1 feed barley, hard red spring wheat and 44% SBM.

[3] Calculated from values obtained from Commerical Solvents Corporation Feed Ingredient Analysis Table, 1973.

[4] Supplies the following per metric ton of mixed feed: 2.33 g cobalt carbonate, 24.77 g copper sulphate, 1.32 g ethylene diamine dehydroiodide, 237.6 g ferrous carbonate, 48.27 g manganous oxide, 2.99 g zinc oxide and 66.84 g limestone.

[5] Supplies the following per metric tone: 4.44g riboflavin, 8.89 g calcium pantothenate, 20.2 niacin, 22.26 g choline chloride, and 0.66 g folic acid.

[6] Supplies 9.90 mg of vitamin B_{12} per metric ton of mixed feed.

[7] Supplies 4,400,000 I.U. vitamin A per metric ton of mixed feed.

[8] Supplies 550,000 I.U. vitamin D_2 per metric ton of mixed feed.

[9] Supplies 11,000 I.U. vitamin E (α - tocopherol) in diets 1, 2, 4 and 5 and 9,900 I.U. in diets 3 and 6 per metric ton of mixed feed.

[10] Supplies 1.5% and 1.0% in diets 3 and 6 respectively on a dry matter basis (of the grain fraction) of "Chemstor" (2/3 acetic, 1/3 propionic acid mixture). Chemcell Ltd., Edmonton, Alberta.

liveweight, except that, in each pen the last pig was marketed following the weekly weigh day on which it reached 85 kg liveweight. All pigs were slaughtered at Swift Canadian Ltd. plant in Edmonton, Alberta. Standard Canadian Carcass Valuation, commonly termed grade index, was determined on each carcass. The formula for Carcass Valuation involves the use of total back fat (maximum shoulder fat and maximum loin fat) and warm carcass weight (Canada Department of Agriculture, 1968). Canadian Record of Performance for swine (R.O.P.) measurements and index as described by Bowland et al. (1971) were determined on all carcasses. A sample of back fat was taken from just under the skin (outer back fat) on the right shoulder adjacent to the midline from each pig at the time the R.O.P. measures were taken. Each back fat sample was placed in a plastic bag, sealed and stored in a frozen condition until analysed for the major constituent fatty acids.

B. Metabolism trials

Metabolism studies were initiated to determine the effects of the different dietary treatments on energy utilization, nitrogen digestibility and retention.

Twenty-four pigs were selected on the basis of treatment and weight on December 30, 1971. Since there were six dietary treatments in the experiment, there were four pigs per treatment, two gilts and two barrows. Six of the eight available metabolism cages were used in the four trials conducted. The cages measured 0.38 m by 1.23 m. The room temperature was approximately 21°C. The trials were conducted on the following dates:

December 31, 1971 - January 6, 1972
January 7, 1972 - January 13, 1972
January 14, 1972 - January 30, 1972
January 21, 1972 - January 27, 1972

Selection and allotment of pigs were such that average weights were similar; that is, the heavier pigs were used in the first two trials and the lighter pigs in the last two. The pigs used had an average age of 80.6 days and average weight of 24.7 kg.

During the trials, the selected pigs were placed in the metabolism cages for a three day period so they could become accustomed to the cages before fecal and urinary collections were started. On the morning of the fourth day, the pigs were removed from the cages and weighed. The cages were thoroughly cleaned with water and the pigs returned. Total urinary and fecal collections were made for the next three days, after which the pigs were removed from the cages, weighed and returned to their respective pens.

During the metabolism trials, records and collection procedures were as follows:

i. Feed

Pigs were fed their respective diets in three equal quantities at 7:30 a.m., 12:00 noon, and 5:30 p.m. during the adjustment and collection periods. In these trials the pigs were fed at a level of 85% of the average daily feed consumed by each pig in the week preceding the metabolism trial. All feed offered was consumed. Feed was analysed separately for each metabolism trial. Approximately 500 g samples were taken on the morning of the first day of the collection period, placed in plastic bags and sealed. For the purposes of energy and nitrogen determinations, the samples were ground with a laboratory mill[1] through a 02 screen[2]. Dry matter content of each diet (for the purpose of

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[1]Arthur H. Thomas Co., Scientific Apparatus, Phila. P.A., U.S.A.

[2] 2 mm

determining feed intake) was calculated based on dry matter values for cereals summarized in Table 2 and dry matter values of the other ingredients in the diets reported in the NRC-NAS United States-Canadian Tables of Feed Composition (1969). A dry matter of 100% was assumed for the dry matter value of individual minerals and vitamins. Dry matter content of the feed samples were determined at the time gross energy analyses were done. Gross energy analyses were on duplicate 1.0 g samples of air-dry feed and these values corrected to a dry matter basis. Approximately 2.0 g samples of feed were analysed for gross N on the same day samples were taken (see methods of chemical analyses).

ii. Feces

Feces were collected each morning during the trial. Each day's collection was placed in a labelled plastic bag and stored at 3°C. At the end of each trial, the total feces collected for each pig were thoroughly mixed, weighed and one sample of approximately 600 g was taken. The samples were placed in an aluminum tray for air-dry matter determination by placing them in a forced air oven[1] at 60°C for 72 hours, removed and allowed to equilibrate to an air-dry basis for 24 hours. These samples were then ground through a size 8 C and N Laboratory mill[2] with a 2 mm mesh screen, placed in labelled plastic bags and sealed. Gross nitrogen determinations were carried out on these samples. Gross energy determinations were done on these samples and these values corrected to dry matter content. Dry matter determinations were carried out at the time gross energy was determined (see method of chemical analyses).

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[1]Despatch Oven Co., Minneapolis, Minn., U.S.A.

[2]Christe and Norris Ltd., Chelmsford, England.

Table 2. Mean moisture and protein contents of the cereal grains[+]

Cereal grain	Moisture	Protein[1]	Protein (DM[2])
	%	%	%
High moisture barley	25.5	8.8	11.8
Low moisture barley	14.2	10.1	11.8
High moisture wheat	19.9	12.9	16.1
Low moisture wheat	14.2	13.8	16.1

1 As fed basis

2 DM - dry matter

+ Based on average analysis of these laboratories: Chemcell Ltd. Edmonton, Alberta; L. Milligan and J. McCarthy, University of Alberta

iii. Urine

Urine collections were made at the same time as the feces were collected. Volume was measured and aliquots were placed in jars, sealed and stored at 3°C so that a total volume of approximately 1000 ml was collected over the three day collection period. Nitrogen content was determined on duplicate 5 ml samples of non-dried urine. Gross energy determinations were made in duplicate on 1.0 g samples of freeze-dried urine (see methods of chemical analyses).

Methods of chemical analyses

A. Dry matter

The dry matter content of the feed and feces were determined by placing duplicate 3.0 g samples of respective materials in a forced air oven[1] for 24 hours at 110°C. The samples were then placed in a desiccator to cool, reweighed, and dry matter calculated by weight difference. Dry matter determinations for the urine was carried out by placing approximately 200 g samples of urine in weighed aluminum trays which were then placed in a freezer dryer[2] for 48 hours, removed, reweighed and dry matter content calculated.

B. Gross energies and nitrogens

Gross energies of feed, feces and urine were determined using a Parr Oxygen Bomb Calorimeter[3]. Gross nitrogen values for feed, feces and urine were determined by the Kjeldahl Method (AOAC, 1965). A commercial Kel-Pak[4] was used in the digestion. Ammonia was collected

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[1] Despatch Oven Co., Minneapolis, Minn., U.S.A.

[2] Repp Sublimator, Model SRC 42, Division of Virtus Co. Inc., Gardener, N.Y. 12525, U.S.A.

[3] Parr Instrument Co., Moline, Ill., U.S.A.

[4] Supplies HgO, K_2SO_4 and $CuSO_4$, Matheson Scientific, East Rutherford, N.J. U.S.A.

into 50 ml of boric acid and titrated directly with standard sulfuric acid.

C. Lipid analyses

i. Extraction

The fat samples were extracted by the method of Folch et al. (1957). A 1.0 g sample was homogenized with 20 ml of $CHCl_3:CH_3OH$ (2:1) in a Virtus "23" homogenizer[1]. The homogenizing vessel was surrounded by ice.

ii. Preparation of methyl esters

Methyl esters were prepared from the extracted lipids by trans-esterification by a slight modification of the method of Morrison and Smith (1964) for triglycerides. N-pentane replaced benzene in this method. The lipid extracts were first filtered through anhydrous Na_2SO_4 to remove any water, the solvent removed under N_2 in a hot water bath and approximately 50 mg of the lipid so obtained transferred to a 150 x 25 mm screw cap culture tube[2] to methanolysis.

iii. Gas-liquid chromatography

Each sample of methyl ester was chromatogrammed singly using an Aerograph Model 600-D chromatograph[3] equipped with a flame ionization detector. Separation of the methyl esters was achieved on a 275 cm x 0.3 cm aluminum column packed with 6% Silar-5-CP[4] on 80-100 mesh chromasorb W. The following isothermal conditions prevailed: column temperature 225°C, injector temperature 255°C, helium flow rate 100 ml per minute.

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[1]Virtus Co., Yonkers, N.Y., U.S.A.

[2]Cat. No. 9826, Corning Glassworks. Fisher Scientific, Edmonton.

[3]Varian Areograph, 2700 Mitchell Drive, Walnut Creek, Calif. 94598, U.S.A.

[4]Applied Scientific Laboratories, 11135 Inglewood Avenue, Inglewood, California, 90304, U.S.A.

iv. Identification of acids

Individual fatty acids were identified by comparing their retention times with the retention times of pure fatty acid methyl esters. The following fatty acids were identified: 14:0, 16:1, 18:0, 18:1, 18:2, 18:3, 20:1[1]. Several other minor components were present; however, these were not identified. The acids 14:0, 16:0, 16:1, 18:0, 18:1 and 18:2 taken together accounted for more than 96% of the fatty acids measured in the samples.

v. Methods of calculation

a. Peak areas

Peak areas were obtained with the aid of an electric integrator[2] attached to the recorder[3].

b. Percent composition

Correction factors for detector response were obtained by chromatogramming each day, a standard sample of known weight percent composition which approximated the composition of porcine depot fat. All correction factors as obtained for a given acid were averaged and applied to chromatograms run on the column to arrive at corrected peak areas. The corrected areas were totaled and the areas of individual acids expressed as a percentage of the total to arrive at weight percent composition.

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[1] 14:0 myristic acid; 16:0 palmitic acid; 16:1 palmitoleic acid; 18:0 stearic acid; 18:1 oleic acid; 18:2 linolenic acid; 18:3 linolenic acid; 20:1 gadoleic acid

[2] Vidar Digital Integrator, Model 6300-2, Autolab Inc., 77 Ortega Ave., Montain view, California, 94040, U.S.A.

[3] Microcord Model 44. Photovolt Corp. 1115 Broadway, New York, N.Y., 10010, U.S.A.

Methods of statistical analysis

All data were analysed using an APL program for analysis of variance developed by the Department of Computing Science (Smillie, 1969), The University of Alberta, Edmonton. Significant differences between three or more means were tested by application of Duncan's New Multiple Range Test (Steel and Torrie, 1960).

Growth and carcass data were analysed as a 2x3x2 factorial experiment with two replicates involving two cereals, three treatments and two sexes. The replicates were confounded with the initial liveweights of the pigs at the time of allotment. A composite error term was used in the analysis of all feed data. For the starting period, replicates and all interactions with replicates were used to calculate the error term. Preliminary testing, using the feed data from the growing-finishing period, showed that interactions with replicates were not statistically significant; therefore, all two-way and higher interactions with replicates were used to compute this error term. A composite error term was used so that the error degrees of freedom would not be reduced by too large a percentage and important differences overlooked. The data collected from the metabolism trials were analysed as 2x3x2 factorial involving two cereals, three treatments and two sexes.

Standard symbols were used to denote levels of statistical significance; that is, * was used to denote significance at the $P<.05$ level and ** was used to denote significance at the $P<.01$ level. These symbols appearing in the tables refer to significance within columns. Where more than two means are compared, means with the same letters as superscipts are not significantlydifferent at the levels indicated. Three-way and higher order interactions are often not explainable and are usually of questionable biological value and are therefore not discussed.

RESULTS AND DISCUSSION

Average daily feed intake (ADF)

Factor means for ADF are reported in Table 3. Cereal source had a significant effect on ADF during the growing-finishing ($P < .01$) and overall periods ($P < .01$). Pigs fed barley ate more than did pigs fed wheat during these periods. Feed consumptions were not significantly different during the starting period for the pigs fed wheat and barley.

Cole et al. (1969) has demonstrated greater intakes of feed by barley-fed pigs compared with wheat-fed pigs during the growing-finishing and overall periods with no significant difference during the starting period. Greater feed consumption by barley-fed pigs compared with pigs fed wheat-based diets have also been reported by Lennon et al. (1972). The greater feed consumption of the barley-fed pigs in the experiment reported herein and in other experiments may be a reflection of the tendency of the pig to eat to meet an energy requirement.

There were no significant differences in ADF due to treatment (LM, LMA and HMA) during any period or for the overall experiment. There were no significant replicate effects in feed consumption although the heavier pigs at allotment in replicate 2 consumed 0.45 kg more feed per day during the starting period than was consumed by the lighter pigs in replicate 1. Sex of the pigs had no significant effect on ADF during the starting period, which was the only period where sexes were separated in different groups. Other studies reported in the literature have not compared sexes.

Treatment of high moisture barley with a VFA mixture did not significantly effect feed consumption when compared with dry barley (Perez-Aleman et al., 1971). Treatment of dry and high moisture sorghum

Table 3. Means for average daily feed (ADF)[1]

Factor	ADF (kg/day) Starter	Grower/Finisher	Overall
Cereal source			
		**	**
Barley	1.41	2.69	2.14
Wheat	1.34	2.13	1.85
Treatment[2]			
LM	1.46	2.53	2.09
LMA	1.35	2.43	2.01
HMA	1.32	2.27	1.89
Replicate			
1	1.15	2.33	1.91
2	1.60	2.49	2.08
Sex[3]			
F	1.35	---	---
M	1.40	---	---

[1] Based on calculated DM intake

[2] LM = low moisture; LMA low moisture, acid treated; HMA = high moisture, acid treated.

[3] F = females (gilts); M = males (barrows).

with a VFA mixture did not significantly effect ADF when compared with dry and high moisture untreated sorghum in work cited by Holden (1972).

Average daily gain (ADG)

Means for ADG appear in Table 4. Growth rates were significantly affected by cereal source. The barley diets supported a faster ($P < .01$) rate of growth than did wheat diets during each of the periods and for the overall experiment. The calculated lysine contents (Table 1) of the wheat diets are well below those suggested as minimum requirements in NRC "Nutrient Requirements of Swine" (1968) for a 20 to 35 kg pig. The apparent deficiency of this amino acid in the wheat diets could account for the slower growth rates of pigs fed these diets during the starting period; however, the lysine contents of the diets approach closely the recommended levels for the finishing pig. Therefore, this amino acid would probably not be limiting during the growing-finishing period. The methionine plus cystine levels (Table 1) were similar for the wheat and barley diets and approached very closely the suggested NRC requirements for methionine for the 20 to 35 kg pig. As both diets contained approximately equivalent levels of these amino acids, it is unlikely that the inferiority of the wheat diets in supporting rates of gain could be attributed to levels of the sulfur-containing amino acids. There is no apparent explanation for the observed slower growth rates of the wheat-fed pigs in the growing-finishing period and the overall experiment. Cole et al. (1969) have demonstrated faster growth rates during the starting and overall periods for barley-fed pigs as compared with wheat-fed pigs in one of four trials. In general growth rates were not different between pigs fed these two cereals from weaning to market weight which is in agreement with Lawrence (1968, 1970) and Lennon et al. (1972)

Table 4. Means for average daily gain (ADG)

Factor	ADG (kg/day) Starter	Grower/Finisher	Overall
Cereal source	* *	* *	* *
Barley	0.51	0.84	0.70
Wheat	0.41	0.67	0.57
Treatment			
LM	0.48	0.78	0.66
LMA	0.46	0.73	0.62
HMA	0.44	0.75	0.62
Replicate	* *	* *	* *
1	0.37	0.70	0.58
2	0.54	0.80	0.69
Sex	* *	* *	* *
F	0.43	0.70	0.60
M	0.49	0.81	0.67

but contrary to the findings of Gill et al. (1966) who found superior growth rates for wheat-fed pigs.

There was no significant effect on ADG due to moisture level and VFA treatment. Replicates and sex had significant effects on ADG. The pigs of replicate 2 gained at a faster rate ($P < .01$) during each of the periods and for the overall experiment. The faster growth rates of the pigs of replicate 2 during the starting period may be in part due to their higher average initial weight at allotment; however, no reason can be advanced for the superior ADG during the growing-finishing and overall periods. The barrows gained at a faster rate ($P < .01$) during each period and overall. It is usual for barrows when fed ad libitum to gain more rapidly than gilts (Bowland, 1966).

VFA treatment of high moisture barley has been shown not to affect ADG of pigs when compared with dry untreated barley (Perez-Aleman et al., 1971, Cole et al., 1970 and Livingstone et al., 1971). Treatment of sorghum with a VFA mixture did not significantly effect ADG of pigs when the mixture was added to both dry and high moisture sorghum as compared with untreated dry and high moisture sorghum in work cited by Holden (1972). Similar results have been reported by Young et al. (1970) for propionic acid treated corn; however, in one of these two trials, acid treatment significantly increased ADG irrespective of moisture content of the corn.

There were significant interactions involving ADG (Table 5). The VFA treatment of wheat diets depressed ADG ($P < .05$) when compared with the other cereal x treatment combinations during the growing-finishing period. Of the four remaining diets, HMAB produced significantly better ($P < .05$) ADG than LMW and LMB with LMAB being intermediate and not significantly different from any of these diets. It would, therefore, appear

Table 5. Means for ADG (kg/day) where significant interactions occurred

ADG growing-finishing period		ADG growing-finishing period		ADG overall period	
LMB[1]	0.81[a]*	R_1F[2]	0.67[a]*	R_1F	0.56[a]*
LMAB	0.84[ab]	R_2F	0.73[a]	R_2F	0.63[b]
HMAB	0.87[b]	R_1M	0.71[a]	R_1M	0.60[ab]
LMW	0.75[a]	R_2M	0.89[b]	R_2M	0.74[c]
LMAW	0.62[c]				
HMAW	0.63[c]				

1 LMB = low moisture barley, LMAB = low moisture acid treated barley, HMAB = high moisture acid-treated barley, LMW = low moisture wheat, LMAW = low moisture acid-treated wheat, HMAW = high moisture acid-treated wheat.

2 R_1F = replicate 1 x female, R_2F = replicate 2 x female, R_1M = replicate 1 x male, R_2M = replicate 2 x male.

that the VFA treatment of wheat depresses rates of gain while the VFA treatment of HMB increased rates of gain when compared with untreated dry grain.

Replicate x sex interactions (Table 5) were noted for ADG during the growing-finishing and overall periods. The barrows of replicate 2 gained at a faster rate ($P < .05$) than did the gilts during the growing-finishing and the overall periods. Differences in ADG during the growing-finishing period for the remaining replicate x sex combinations were not significant. However, during the overall period the gilts of replicate 2 gained at a faster rate ($P < .05$) than replicate 1 gilts with replicate 1 barrows being intermediate and not significantly different from these two. There is no evident explanation for these replicate x sex interactions.

Feed conversion efficiency (F/G)

Factor means for efficiency of feed conversion are tabulated in Table 6. Cereal source had a significant effect on F/G. Barley-fed pigs converted feed to liveweight gain more efficiently than wheat-fed pigs during the starting period ($P < .01$) and overall period ($P < .01$) with no significant difference during the growing-finishing period. The superiority of barley during the starting period might have been the result of a lysine deficiency in the wheat diets. The reasons for the superiority of barley during the overall period are not apparent. Lawrence (1968) has reported significantly better F/G during the starting period for barley-fed pigs compared with those fed wheat; however, the F/G of the barley and wheat-fed pigs were not significantly different in later stages of growth. In similar studies, Newman et al. (1966) found no significant difference in F/G during the starting and overall periods

Table 6. Means for efficiency of feed conversion[1]

Factor	Feed conversion (kg feed/kg gain)		
	Starter	Grower/Finisher	Overall
Cereal source			
	**		**
Barley	2.75	3.25	3.10
Wheat	3.40	3.30	3.30
Treatment			
		*	
LM	3.16	3.30[a]	3.22
LMA	2.94	3.40[a]	3.27
HMA	3.13	3.13[b]	3.10
Replicate			
		*	**
1	3.20	3.38	3.31
2	2.95	3.18	3.09
Sex			
F	3.21	---	---
M	2.95	---	---

[1] Based on calculated DM intake

with greater F/G during the finishing period for pigs fed wheat. Lawrence (1970) found no significant differences in F/G between these cereals during the starting, finishing and overall periods while Gill et al. (1966), Lennon et al. (1972) and Crampton and Ashton (1945) found that wheat produced more efficient gains on a unit weight of feed basis than was produced by barley.

Treatments had a significant effect on F/G during the growing-finishing period. Pigs fed HMA diets converted feed more efficiently (P .05) than did pigs on LM and LMA diets which did not differ in efficiency of feed conversion. Replicate had a significant effect on F/G during the growing-finishing and overall periods. The pigs of replicate 2 converted feed to liveweight gain more efficiently during the growing-finishing period (P .05) and overall (P .01). There is no apparent explanation for the superiority of one replicate over another in terms of F/G. Sex had no effect on F/G during the starting period when this effect could be measured.

Treatment of dry and high moisture sorghum with a VFA mixture had no significant effect on F/G in pigs when compared with untreated dry and high moisture sorghum in work cited by Holden (1972). VFA treatment of high moisture barley has been shown not to significantly effect F/G when compared with dry untreated barley (Cole et al., 1970; Livingstone et al., 1971 and Perez-Aleman et al., 1971). Young et al. (1970) has reported superior F/G of high moisture corn and high moisture corn treated with propionic acid compared with dry untreated corn.

Carcass characteristics

Factor means for slaughter age and carcass data are tabulated in

Table 7. Cereal source had a significant effect on several carcass measurements. Barley-fed pigs were of younger ($P < .01$) age at market weight which is directly associated with significantly greater ADG demonstrated by these pigs compared with those fed wheat. Barley-fed pigs had a lower dressing percentage ($P < .01$), greater loin areas ($P < .01$), a larger percentage of ham in the carcass ($P < .01$) and higher R.O.P. ($P < .01$) and grade ($P < .05$) indices, all of which are indicative of leaner carcasses. Cereal source did not significantly affect the other carcass measures. Hollis and Palmer (1971) and Cole et al. (1969) have reported lower dressing percentages for barley-fed pigs compared with wheat-fed pigs. Other workers have also noted a lower percentage of ham in the carcasses of wheat-fed pigs (Hollis and Palmer, 1971) as well as lower grades (Crampton and Ashton, 1945). Total back fat was not affected by cereal source which is in agreement with Gill et al. (1966) and Lawrence (1970).

Treatments had no significant effects on carcass measurements; however, slaughter ages of the pigs on LM diets were less ($P < .01$) than those on LMA and HMA diets. LMA and HMA slaughter ages were not significantly different. These differences in slaughter age are associated with the non-significantly slower growth rates of the LMA and HMA fed pigs compared with the LM pigs.

High moisture barley has been shown not to affect average back fat thickness and loin eye area (Livingstone and Livingston, 1970) or gross carcass composition as measured by specific gravity (Livingstone and Livingston, 1970; Forbes et al., 1964). Addition of 2% to 12% of a VFA mixture to dry diets of pigs as well as addition of 4% of a VFA mixture to dry diets have been shown to have no significant effect on hot carcass

Table 7. Means for slaughter age and carcass data

Factor	Slaughter age days	Carcass weight kg	Dressing %	Total back fat[1] cm.	Loin area sq. cm.	Ham/ carcass %	Lean in ham face %	Lean area ham/ ham weight sq. cm./kg.	Carcass length cm.	ROP index	Grade index
Cereal source	**		**		**	**				**	*
Barley	161.3	72.6	79.3	10.6	31.0	26.7	48.8	14.2	77.0	67.8	101.1
Wheat	188.0	73.2	80.5	11.2	23.9	25.9	45.2	13.7	77.2	65.2	99.3
Treatment	*										
LM	167.8[a]	72.8	79.7	10.7	28.4	26.4	47.2	13.6	76.5	66.7	101.4
LMA	176.6[b]	73.5	80.5	11.1	27.4	26.6	46.4	13.8	77.5	66.2	99.6
HMA	179.7[b]	72.4	79.6	10.9	26.6	26.0	47.3	14.4	77.2	66.7	99.7
Replicate	**	**	**	*	*					**	
1	184.0	75.1	81.7	11.3	26.4	26.1	45.7	13.4	77.4	65.3	99.9
2	165.4	70.7	78.1	10.4	28.6	26.6	48.3	14.4	76.7	67.8	100.6
Sex	**			**	*	*				*	*
F	179.9	72.1	79.9	10.4	28.7	26.7	48.5	13.9	77.1	67.6	101.1
M	169.4	73.7	79.9	11.4	26.3	26.0	45.5	13.9	77.1	65.5	99.4

[1] Three measurements (maximum shoulder, minimum midback and maximum loin)

weight, dressing percentage, grade index, average back fat thickness, loin eye area and percent lean in the ham face (Bowland et al., 1971). VFA preservation of high moisture barley did not significantly effect gross carcass composition as measured by specific gravity in work reported by Livingstone et al. (1971). Cole et al. (1970) has reported no significant effects of VFA preservation of high moisture barley on killing-out percentages, carcass length, shoulder and loin fat thickness and loin eye area.

There were significant differences between replicates for several carcass measurements and slaughter age. Replicate 1 pigs reached market weight at an older age than did pigs of replicate 2. The pigs of replicate 1 had heavier carcass weights ($P < .01$), greater dressing percentages ($P < .01$), more total back fat ($P < .05$), small loin areas ($P < .05$) and inferior R.O.P. indices ($P < .01$) to those in replicate 2. Pigs in replicate 1 converted feed less efficiently than those in replicate 2 which may be related to the differences in carcass measurements between the replicates.

Sex of the pigs had a significant effect on carcass measures as well as slaughter age. Barrows reached market weight at a younger average age ($P < .01$). Gilts had less total back fat ($P < .01$), greater loin eye areas ($P < .05$), a larger percentage of ham in the carcass ($P < .05$) and better R.O.P. ($P < .05$) and grade ($P < .05$) indices than barrows. The superior R.O.P. index and grade index of the gilts are indicative of the ability of gilts to produce leaner carcasses than barrows (Bowland, 1966). Slaughter age was affected by several interactions. (Table 8) LMAW and HMAW fed pigs were slaughtered at a similar age but both reached market weight at an older age ($P < .05$) than did pigs on the other

Table 8. Means for carcass data where significant interactions occurred

Factor[1]	Loin area sq. cm.		Carcass weight[2] kg.		Carcass length[1] cm.
	*		*		*
LMB	32.1[a]	LMF	70.7[a]	LMB	76.9[ab]
LMAB	32.5[a]	LMM	74.9[b]	LMAB	77.8[ab]
HMAB	28.5[b]	LMAF	72.8[b]	HMAB	76.2[b]
LMW	24.8[c]	LMAM	74.3[b]	LMW	76.2[b]
LMAW	22.4[c]	HMAF	73.0[b]	LMAW	77.1[ab]
HMAW	24.6[c]	HMAM	71.9[b]	HMAW	78.2[a]

	Carcass length[3] cm.		Slaughter age[1] days		Slaughter age[4] days
	*		*		**
R_2M	75.8[a]	LMB	161.9[bc]	R_1B	164.4[ab]
R_1M	76.5[ab]	LMAB	161.9[bc]	R_2B	158.2[b]
R_2F	77.6[bc]	HMAB	160.1[c]	R_1W	203.5[c]
R_1F	78.4[c]	LMW	173.6[b]	R_2W	172.6[a]
		LMAW	191.2[a]		
		HMAW	199.2[a]		

	Slaughter age[5] days
	*
BF	162.6[a]
BM	160.0[a]
WF	197.2[b]
WM	178.8[c]

[1] Cereal x treatment — LM, LMA, HMA x B, W

[2] Treatment x sex — LM, LMA, HMA x F, M

[3] Replicate x sex — R_1, R_2 x F, M

[4] Replicate x cereal — R_1, R_2 x B, W

[5] Cereal x sex — B, W x F, M

LM = low moisture; LMA = low moisture acid; HMA = high moisture acid; B = barley; W = wheat; F = female; M = male; R = replicate

cereal x treatment groups. Of the latter four groups, pigs on LMW diets reached market weight at an older age ($P < .05$) than did HMAB-fed pigs while LMAB and LMB pigs were intermediate and not of significantly different age at slaughter compared with HMAB and LMW-fed pigs. The R_1W fed pigs reached market weight at an older age ($P < .01$) than did pigs on the other cereal x replicate groups. Of the remaining groups, pigs on R_2W diets reached market weight at an older age ($P < .01$) than R_2B fed pigs with R_1B pigs being intermediate and not significantly different from either. For the cereal x sex interactions, BF and BM groups reached market weight at an earlier age ($P < .05$) than did WM and WF groups. WM pigs reached market weight at an earlier age ($P < .05$) than did WF pigs. These differences in slaughter age may be explained in part by the differences in growth rates (Table 9), although differences in ADG for these interactions were not significant.

Several significant interactions were noted for some carcass measures (Table 9). Loin areas of LMB and LMAB-fed pigs were significantly larger ($P < .05$) than the pigs on the other diets. Of the remaining four diets, HMAB-fed pigs had larger loin areas ($P < .05$) than the pigs fed any of the wheat x treatment combinations which were not significantly different. The reasons for the smaller loin area of HMAB diets compared with LMAB and LMB diets is not apparent. Bowland et al. (1971) have reported no significant effects on loin area due to VFA treatment of dry diets which is in agreement with the findings herein reported. Livingstone and Livingston (1970) have reported no significant differences in loin area between dry and high moisture barley diets.

Carcass weights were affected by a treatment x sex interaction. Gilts fed LM diets had lighter carcass weights ($P < .05$) than did pigs

Table 9. Means for ADG for slaughter age interactions

Factor	ADG overall kg/day	Factor	ADG overall kg/day
LMB	0.69	R_1B	0.66
LMAB	0.69	R_2B	0.74
HMAB	0.69	R_1W	0.51
LMW	0.60	R_2W	0.64
LMAW	0.54		
HMAW	0.51		

Factor	ADG overall kg/day
BF	0.67
BM	0.72
WF	0.52
WM	0.62

of the other treatment x sex combinations. Carcass length was affected by cereal x treatment and replicate x sex interactions. HMAW-fed pigs had longer carcasses ($P < .05$) than did HMAB and LMW-fed pigs but were not different from LMB, LMAW and LMAB-fed pigs. All pigs except those fed HMAW diets were not significantly different for this measure.

Fatty acid composition of back fat

Means for fatty acid composition of the back fat appear in Tables 10 and 11. Fatty acid composition of the back fat was affected by cereal source. Pig fed barley-fed diets produced carcasses with a larger proportion of 14:0 ($P < 0.1$) and 18:2 ($P < .05$) and less 18:1 ($P < .01$) in the back fat than wheat-fed pigs. The LM treatment had a higher proportion of 14:0 ($P < .01$) in the back fat compared with HMA treatment. For the LMA treatment, the proportion of this fatty acid was intermediate between the other two treatments. Replicate 1 pigs contained a smaller proportion of 18:2 ($P < .01$) and a larger proportion of 20:1 ($P < .01$) fatty acids in their back fat than did pigs of replicate 2. Sex also had an effect on fatty acid composition of the back fat. Gilts had a larger proportion of 18:2 ($P < .01$), 18:3 ($P < .01$) and 20:1 ($P < .05$) in their back fat than did barrows.

The sums of the saturated fatty acids (14:0, 16:0, 18:0) (SFA) and the unsaturated fatty acids (16:1, 18:1, 18:2, 18:3, 20:1) (UFA) in the back fat were affected by cereal source. The barley-fed pigs had more ($P < .05$) SFA and concomitantly less UFA ($P < .05$) than did wheat-fed pigs. Treatment had no significant effect on the relative proportions of SFA and UFA. There were no differences due to replicate in SFA and UFA proportions. The sex of the pig affected the SFA and UFA proportions with gilts having less SFA ($P < .01$) and more UFA ($P < .01$) in the back fat.

Table 10. Means for percent fatty acid composition of outer backfat

Fatty Acids[1]	14:0	16:0	16:1	18:0	18:1	18:2	18:3	20:1
Cereal Source	**				**	*		
Barley	3.0	24.3	4.8	10.0	47.0	9.7	0.5	0.7
Wheat	2.1	23.8	4.4	10.0	49.2	9.1	0.4	0.9
Treatment	**							
LM	3.1[a]	23.9	4.6	10.2	47.5	9.4	0.5	0.8
LMA	2.4[ab]	24.1	4.6	9.8	48.4	9.6	0.4	0.7
HMA	2.2[b]	24.3	4.6	10.0	48.4	9.2	0.4	0.8
Replicate						**		**
1	2.6	24.3	4.5	10.0	48.6	8.7	0.4	0.9
2	2.5	23.8	4.7	10.0	47.6	10.1	0.5	0.7
Sex		**				**	**	*
F	2.5	23.3	4.5	9.9	48.3	10.0	0.6	0.9
M	2.6	24.8	4.7	10.1	47.9	8.8	0.3	0.7

[1] 14:0 myristic acid; 16:0 palmitic acid; 16:1 palmitoleic acid; 18:0 stearic acid; 18:1 oleic acid; 18:2 linoleic acid; 18:3 linolenic acid; 20:1 gadoleic acid.

Table 11. Means for sums of percent saturated and unsaturated fatty acids

Fatty Acids	Sum of saturated 14:0+16:0+18:0	Sum of unsaturated 16:1+18:1+18:2+18:3+20:1
Cereal Source	*	*
Barley	37.3	62.7
Wheat	36.0	64.0
Treatment		
LM	37.2	62.8
LMA	36.2	63.8
HMA	36.5	63.5
Replicate		
1	36.9	63.1
2	36.4	63.6
Sex	* *	* *
F	35.7	64.3
M	37.6	62.4

There are little comparable data in the literature with which fatty acid composition of back fat can be compared. Lawrence (1970) found that barley-fed pigs contained similar amounts of UFA in the outer back fat compared with wheat-fed pigs at 55 kg liveweight. At 90 kg liveweight, however, barley-fed pigs had more UFA in their back fat than wheat-fed pigs. Bowland et al. (1971) have reported that pigs fed diets containing 4% by weight of a VFA mixture had a greater proportion ($P < .05$) of 18:1 fatty acid than did control pigs. The SFA and the major UFA (16:1 + 18:1 + 18:2) were not affected by VFA treatment.

Significant interactions involving fatty acids 14:0 and 18:2 were noted (Table 12). Pigs fed LMB diets had a greater proportion of 14:0 in their back fat ($P < .01$) than those on the other cereal x treatment groups. Gilts fed LM diets contained more 14:0 ($P < .05$) in their back fat than did gilts and barrows fed LMA and HMA diets or barrows fed LM diets. The proportion of 18:2 in the back fat was affected by cereal x replicate interactions. R_2B pigs had more ($P < .05$) 18:2 in the back fat than did pigs fed the other cereal x replicate combinations. There are no apparent reasons for many of these complex interactions.

Metabolism experiments

Factor means for DN and RN are tabulated in Table 13. During the 3-day metabolism experiments, daily feed intakes were not significantly different between pigs fed the barley and wheat-based diets. No significant differences due to cereal source were noted for DN(g), RN(g) and RN(%). DN(%) was significantly greater ($P < .05$) for wheat-based diets and RN(%) was smaller ($P < .05$) for wheat-based diets than for barley diets. The feed intakes of pigs fed HMA diets were less ($P < .05$) than for HMA diets with LMA diets being intermediate and not different from either.

Table 12. Means for weight percentage of fatty acids in outer backfat where significant interactions occurred

14:0	**	14:0	*	18:2	
LMB	4.3[a]	LMF	3.5[a]	R_1B	8.6[a]
LMAB	2.4[b]	LMM	2.7[b]	R_2B	10.8[b]
HMAB	2.8[b]	LMAF	2.1[b]	R_1W	8.7[a]
LMW	1.9[b]	LMAM	2.6[b]	R_2W	9.4[a]
LMAW	2.4[b]	HMAF	1.8[b]		
HMAW	2.2[b]	HMAM	2.6[b]		

Table 13. Means for N-digestibility (DN) and N-retention (RN)[1]

Factor	Daily feed g	DN g/day	DN %	RN/ N intake %	RN/ N intake %	RN/DN %
Cereal source			*			*
Barley	1235	91.3	80.7	63.6	56.2	69.5
Wheat	1239	103.3	88.1	62.3	53.0	60.0
Treatment	*					
LM	1320[a]	104.5	84.0	73.2	58.9	70.0
LMA	1265[ab]	99.5	84.1	60.0	50.9	60.5
HMA	1166[b]	87.8	85.2	55.8	54.0	63.6
Sex						
F	1244	90.0	81.6	59.8	54.0	66.2
M	1230	104.5	87.2	66.2	55.2	63.3

[1] 100% DM basis (based on calculated DM intake)

Treatment and sex had no significant effects on N digestibilities and retentions.

Cornejo et al. (1973) reported no significant differences in RN of gross N(%) and increased RN of DN(%) for pigs fed barley compared with wheat when these cereals were the only source of protein and energy for the pig. Cole et al. (1970) reported that VFA treatment of high moisture barley produced similar apparent digestibility coefficients for N compared with dry untreated barley. Apparent protein digestibility coefficient (%), N-retention per day and N-retention (% of gross N) were not affected by addition of water to the feed of barrows (Kornegay and Graber, 1968).

The DE and ME contents of the wheat diets were greater ($P < .01$) than those of the barley diets (Table 14). This would be expected on inspection of values in the NRC Feed Composition Tables (1969). The DE as a percent of gross energy was greater ($P < .01$) for the wheat-based diets compared with the barley-based diets. ME as a percent of DE was not affected by cereal source. The DE and ME contents of the HMA diet was lower ($P < .05$) than the LM and LMA diets which were not different. DE as a percent of gross energy and ME as a percent of DE were not affected by treatment. Sex of the pigs had no significant effect on any of the measures of digestibilities.

Cornejo et al. (1973) reported that ME/DE(%) was not significantly different for wheat and barley. The apparent digestibility coefficient of gross energy was not affected by VFA treatment of high moisture barley when compared with dry barley (Cole et al., 1970). Kornegay and Graber (1968) have reported that the energy digestibility coefficient was not affected by addition of water to diets based on corn.

Table 14. Means for digestible energy (DE) and metabolizable energy (ME)[1]

Factor	DE/kg feed kcal	DE/GE %	ME/kg feed kcal	ME/DE %
Cereal source	**	**	**	
Barley	3121	78.5	3039	97.4
Wheat	3461	86.5	3357	97.0
Treatment	*		*	
LM	3426[a]	83.1	3348[a]	97.7
LMA	3335[ab]	82.3	3228[ab]	96.8
HMA	3112[b]	82.1	3018[b]	97.0
Sex				
F	3239	80.2	3165	97.7
M	3342	84.8	3232	96.7

[1] 100% dry matter basis (based on calculated DM intake)

GENERAL SUMMARY AND CONCLUSIONS

Pigs fed barley-based diets consumed more feed per day, gained at a faster rate and converted feed to liveweight gain more efficiently than did pigs fed wheat-based diets. Calculated lysine levels of the wheat diets were below the minimum requirement suggested for the starting pig; however, the lysine contents of the wheat diets approached the recommended levels for the finishing pig.

The addition of volatile fatty acids (acetic-propionic acid mixture) to the diets had no significant effects on feed intake, rates of gain and feed conversion efficiencies. It would appear that VFA, which are effective preservatives for high moisture content grains, do not adversely effect performance of pigs when the acids are in their diets.

The digestibility and retention data gave little information that could be related directly to performance or carcass quality of the pigs. Grams of N digested and retained were not different for wheat or barley diets. N digestibility (%) was greater for wheat diets; however, RN/DN(%) was lower for the wheat diets. DE and ME contents of the diets followed the same pattern. Sex of pigs had no significant effects on digestibilities and retentions.

Carcass characteristics were affected by cereal source. Barley-fed pigs had a lower dressing %, increased loin areas, greater ham/carcass % and superior R.O.P. and grade indices. Barley-fed pigs also reached market weight at an earlier age than wheat-fed pigs. The usual trend is for pigs that gain more rapidly to have fatter carcasses, but in the present experiment the opposite situation occurred. It is also usual for pigs fed higher energy diets based on a wheat compared with lower energy diets based on barley to have fatter carcasses and this situation

did exist. Carcass characteristics were not affected by treatments; however, pigs on the low moisture diets reached market weight at a younger age than did pigs on the other treatments.

The back fat of the barley-fed pigs contained more 14:0 and 18:2 fatty acids and less 18:1 than wheat-fed pigs. The barley-fed pigs had a larger proportion of saturated fatty acids and concomitantly less unsaturated fatty acids in their back fat than did wheat-fed pigs. Treatments affected the proportion of 14:0; low moisture diets producing a larger proportion of 14:0 than high moisture acid-treated diets, with low moisture acid-treated diets being intermediate. Treatments did not affect the proportions of the other fatty acids.

Sex had a significant effect on slaughter age, certain carcass measures and fatty acid composition of the back fat. Gilts had less total back fat, larger loin areas, greater ham/carcass percentage and better R.O.P. and grade indices. Gilts reached market weight at an older age than barrows. These are the usual differences encountered between gilts and barrows. Gilts produced smaller proportions of 16:0 and greater proportions of 18:2 and 18:3 which resulted in more unsaturated and concomitantly less saturated fatty acids in their back fat.

The addition of volatile fatty acids to pig diets did not significantly affect performance or carcass quality although age at slaughter was older for pigs fed acid-treated diets by approximately 10 days. This difference in market age was related to wheat-based diets as there was little evidence of difference in barley-based diets. Therefore, based on results obtained, use of the VFA mixture (2/3 acetic, 1/3 propionic acids) used in this trial as preservative for barley will not interfere with performance of pigs fed diets containing the barley with the preservative. Further study of preserved wheat is needed before

use of such wheat can be recommended without any possible reservation even though VFA treatment of wheat had no significant effects on performance.

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APPENDICES

Table i. Mean squares - feed and growth data

Factor	df	Average daily gain (ADG) Starter	Grower/Finisher	Overall
Cereal (C)	1	0.1262**	0.3537**	0.1851**
Treatment (T)	2	0.0077	0.0099	0.0062
CT	2	0.0058	0.0404*	0.0060
Sex (S)	1	0.0480**	0.1548**	0.0720**
CS	1	0.0040	0.0115	0.0077
TS	2	0.0016	0.0102	0.0014
CTS	2	0.0017	0.0117	0.0032
Replicate (R)	1	0.3696**	0.1198**	0.1267**
RC	1	0.0143	0.0297	0.0086
RT	2	0.0003	0.0050	0.0025
RCT	2	0.0117	0.0055	0.0091
RS	1	0.0203	0.0378*	0.0189*
RCS	1	0.0060	0.0082	0.0012
RTS	2	0.0071	0.0107	0.0052
RCTS	2	0.0030	0.0077	0.0019
Error	24	0.0055	0.0076	0.0041
Total	47			

Factor	df	Average daily feed (ADF) Starter
Cereal (C)	1	0.0235
Treatment (T)	2	0.0421
CT	2	0.0072
Sex (S)	1	0.0153
CS	1	0.0121
TS	2	0.0233
Error	14	0.1044
Total	23	

Table i. continued

Factor	df	Average daily feed (ADF) Grower/Finisher	Overall
Cereal (C)	1	0.9172**	0.2578**
Treatment (T)	2	0.0661	0.0419
CT	2	0.0670	0.0120
Replicate	1	0.0748	0.0908
Error	5	0.0414	0.0157
Total	11		

Table ii. Mean squares - efficiency of feed conversion (F/G)

Factor	df	Efficiency of feed conversion (F/G)
		Starter
Cereal (C)	1	2.5424**
Treatment (T)	2	0.1078
CT	2	0.1437
Sex (S)	1	0.4224
CS	1	0.0039
TS	2	0.2336
Error	14	0.1682
Total	23	

Factor	df	Efficiency of feed conversion (F/G)	
		Grower/Finisher	Overall
Cereal (C)	1	0.0072	0.1205**
Treatment (T)	2	0.0726*	0.0281
CT	2	0.0095	0.0010
Replicate	1	0.1143*	0.1480**
Error	5	0.0074	0.0074
Total	11		

Table iii. Mean squares - fatty acid composition of outer backfat

		Individual fatty acids							
Factor	df	14:0	16:0	16:1	18:0	18:1	18:2	18:3	20:1
Cereal (C)	1	8.644**	2.548	1.254	0.006	55.148**	4.896*	0.070	0.4015
Treatment (T)	2	3.576**	0.684	0.002	0.616	4.963	0.701	0.035	0.814
CT	2	7.171**	1.639	1.065	2.431	3.939	0.181	0.458	0.0644
Sex (S)	1	0.239	29.047**	0.437	0.476	1.972	16.136**	1.740**	0.2394*
CS	1	0.783	4.588	0.099	0.429	0.338	0.494	0.022	0.0002
TS	2	2.940*	0.876	0.865	0.056	5.640	0.771	0.056	0.0070
CTS	2	3.857**	4.050	0.432	2.165	7.270	0.604	0.135	0.0665
Replicate (R)	1	0.071	2.385	0.512	0.033	11.184	22.950**	0.154	0.8560**
RC	1	1.271	1.779	0.456	0.037	2.562	6.623*	0.460	0.1074
RT	2	0.806	0.380	0.351	0.607	0.790	1.277	0.074	0.0298
RCT	2	1.482	4.356	0.847	0.542	14.692*	0.232	0.033	0.0975
RS	1	2.489	2.271	1.274	1.414	1.181	2.021	0.036	0.1055
RCS	1	0.119	2.193	0.407	1.748	0.117	0.932	0.310	0.0020
RTS	2	0.483	3.206	1.035	1.180	4.300	1.707	0.159	0.2633*
RCTS	2	0.220	8.800*	0.211	0.296	2.932	0.524	0.157	0.1116
Error	24	0.612	2.048	0.377	1.107	2.928	1.097	0.174	0.0543
Total	47								

Table iii. continued

		Sums of saturated and unsaturated fatty acids	
Factor	df	14:0+16:0+18:0	16:1+18:1+18:2+18:3+20:1
Cereal (C)	1	19.905*	19.905*
Treatment (T)	2	3.397	3.397
CT	2	4.631	4.631
Sex (S)	1	43.149**	43.149**
CS	1	0.362	0.362
TS	2	0.334	0.334
CTS	2	10.303*	10.303
Replicate (R)	1	2.655	2.655
RC	1	7.046	7.046
RT	2	0.521	0.521
RCT	2	12.721*	12.721*
RS	1	3.592	3.592
RCS	1	6.042	6.042
RTS	2	6.093	6.093
RCTS	2	7.932	7.932
Error	24	2.747	2.474
Total	47		

Table iv. Mean squares - metabolism data for N-digestibility and N-retention

Factor	df	Daily feed	DN g	N-digestibility %	N-retention of gross N g	N-retention of gross N %	N-retention of DN %
Cereal (C)	1	652.084	861.602	325.091*	10.948	60.167	543.782*
Treatment (T)	2	718379.0*	588.103	3.655	658.740	131.305	188.522
CT	2	19828.9	49.842	12.290	14.388	21.127	15.166
Sex (S)	1	174677.0	689.51	70.213	541.595	114.581	20.572
CS	1	210.6	115.019	9.040	40.274	101.188	212.653
TS	2	11388.1	99.948	13.811	6.356	64.896	52.202
CTS	2	123976.0	595.569	51.620	518.401	121.302	64.160
Error	12	164456.0	264.328	37.401	204.883	99.454	82.784
Total	23						

Table v. Mean square - metabolism data for digestible and metabolizable energy

Factor	df	DE/kg feed kcal	DE/GE %	ME/kg feed kcal	ME/DE %
Cereal (C)	1	693992.0**	385.599**	606696.0**	1.0366
Treatment (T)	2	209437.0*	2.428	222988.0*	1.9138
CT	2	54184.0	15.858	56461.7	0.1164
Sex (S)	1	59152.8	49.563	52359.6	0.1011
CS	1	60.659	6.562	203.832	0.4113
TS	2	75400.0	51.381	83356.6	0.6458
CTS	2	49749.8	39.186	53658.1	0.1909
Error	12	33711.7	26.654	35448.3	1.1011
Total	23				

Table vi. Mean squares - slaughter age and carcass data

Factor	df	Slaughter age	Dressing %	Total back fat	Loin area	Ham/ Carcass	Lean in ham face	Lean area ham/ ham weight	Carcass length	ROP	Grade index
Cereal (C)	1	8586.75**	17.133**	0.5633	14.4431**	8.1098**	154.657	0.01145	0.0533	81.172**	38.5208*
Treatment (T)	2	613.146*	3.572	0.1065	0.3167	1.1750	4.3628	0.01336	0.6033	1.2676	17.5833
CT	2	770.062*	0.989	0.2277	0.9337*	1.1185	40.688	0.00455	1.6133*	6.0759	5.5833
Sex (S)	1	1323.0**	0.031	2.0833**	1.6763*	5.4069*	105.851	0.0	0.0008	51.212*	35.0208**
CS	1	752.083*	0.007	0.0133	0.2015	0.2868	37.3121	0.00458	0.0008	1.3134	0.5208
TS	2	71.688	6.598	0.0590	0.2878	1.7516	15.8114	0.01684	1.1408	3.6392	14.5833
CTS	2	53.271	0.139	0.0627	0.1865	0.2394	14.2474	0.00642	0.0658	0.6190	2.3333
Replicate (R)	1	4144.083**	158.701**	1.45*	1.3568*	2.5622	80.0833	0.05701	1.0208	75.953**	6.0208
RC	1	1825.33**	1.579	0.27	0.4982	0.2837	0.1452	0.00003	0.8008	6.7951	3.5208
RT	2	375.646	0.608	0.0356	0.4912	1.6581	31.1472	0.00483	0.2233	4.8165	1.0833
RCT	2	370.896	3.163	0.0394	0.2777	0.1555	14.8122	0.02604	0.3033	7.1451	2.0833
RS	1	200.083	0.970	0.1633	0.0315	0.4238	0.1541	0.00362	6.4533*	0.2160	6.0208
RCS	1	12.0	1.763	0.03	0.1716	0.7475	63.572	0.05497	1.47	9.2752	6.0208
RTS	2	377.521	4.097	0.0190	0.6056	0.3222	7.532	0.01121	0.5208	3.1814	6.0833
RCTS	2	82.938	1.126	0.1019	0.1001	1.2635	39.9944	0.01931	0.4825	8.882	12.3333
Error	24	141.375	1.983	0.1888	0.2504	0.7259	37.7384	0.02489	0.4421	6.5764	6.8958
Total	47										